ADVANCED DRIVER AIRBAG SYSTEM.

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1. ABSTRACT

New improvements in driver safety systems need to guarantee higher control on all crash parameters such us offset crashes with non longitudinal movements and crashes with steering column movements. New shapes of bags combined with systems that fix the position of the bag can do this work.

Steering systems have made that the normal shape of driver airbags DAB had been designed round or very near to this shape. In this work are presented the results of a new development in new shapes that with new mechanical (or electromechanical) steering solutions could be installed in future vehicles.

There have been studied new shapes that reduce the probability of injuries in head and thorax and that optimise the restraint effect. Also have been developed shapes that show clear benefits in the case of non desired movements of the steering wheel and column in frontal collisions. In these kind of accidents thorax injuries can be produced by the impact with the steering wheel rim new shapes of the bag combined with systems that guarantee the same bag position in all crash configurations.

The main objective is to reduce the kinetic energy of the drivers at the early moments of the crash, improving the restraint and avoiding hard contacts of the occupant body with the steering wheel. To achieve this objective the new proposed geometries have the target of restraining the arms of drivers reducing the forces transmitted to the body. This reduction have the target of decreasing the accelerations of drivers Head and Thorax.

The work will show that this main objective is fulfilled with a good rate of success.

2. METHODOLOGY

The present work analyses the influence in the restraint of different asymmetric shapes or geometries of bags in comparison with symmetric ones round geometry and rectangular geometry. **Figure 1.** show the different shapes studied.

The results of the system performances have been analysed for two different situations of the crash, vehicle without steering wheel intrusion and vehicle with steering wheel intrusion.

Two different vehicles with different crash pulses have been used in the initial comparison between round and rectangular shape.

The comparison has been made by simulation of the different configurations and the validation of the models have been made with static, body-block and sled tests.

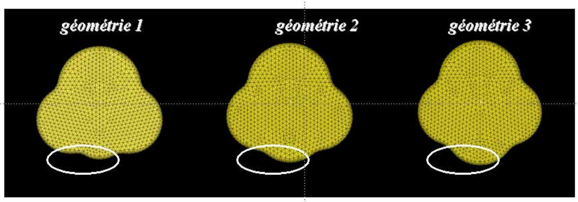

Figure 1. New geometries analysed.

In order to avoid the influence of external parameters to the ones that had been selected there was used only one inflator model for the simulation and testing.

Also the volume of the bag was the same in all the five configurations or designs of bags.

For the analysis of results it has been used the Euro-NCAP injury criteria, and the main Force and Acceleration curves of each solution. **Tables 1, 2 and 3** show the resume of the results of each configuration analysed.

3. ACCIDENT ANALYSIS:

Previous to the work of analysis of the dynamics of the dummies involved in a crash with defined circumstances, it has been reviewed the distribution of injuries in relationship with steering column intrusion.

For this work it has been analysed the NASS CDS (National Accident Sampling Systems, Crashworthines Data System) looking for the severity due to steering column movements.

It has been selected all crashes with intrusion of the steering wheel intcomp1 to intcomp10 equal to 01. And the magnitude of the intrusion has been set into one variable int-vol. Also for these analysis there have been selected only drivers occupant role = 01.

Figure 2 represents the percentage distribution of all injuries (1 to 6) in A.I.S[2] severity code, in relation with variables magnitude of steering wheel intrusion and airbag system deployed for this position. Figure 3 shows the same distribution classified for each A.I.S. injury code value.

Int-vol codification takes values from 1 to 6 with the following meaning:

1 ⇒ 3 cm ≤ intrusion < 8 cm
2 ⇒ 8 cm ≤ intrusion < 15 cm
3 ⇒ 15 cm ≤ intrusion < 30 cm
4 ⇒ 30 cm ≤ intrusion < 46 cm
5 ⇒ 46 cm ≤ intrusion < 61 cm
6 ⇒ 61 cm ≤ intrusion .

Airbag system deployment values have the following meaning:

0 ⇒ Not equipped/Non available.
1 ⇒ Deployed during accident (as a result of impact)
7 ⇒ Nondeployed.
2 to 6 and 9 deployed as a result of events different to impact or Unknown.

Once defined the variables taken into account in the study it has to be appreciated that in crashes with intrusion of the steering wheel there are higher number of injured occupants for intrusion magnitudes 2 or 3 than for 1. This fact is very significant because crashes with intrusion values of 1 are more frequent than with those other values.

Another fact that has to be analysed is that the same distribution is present for vehicles with driver airbag deployed. This means that intrusion events increase the severity of injuries in both situations (airbag deployed and not deployed).

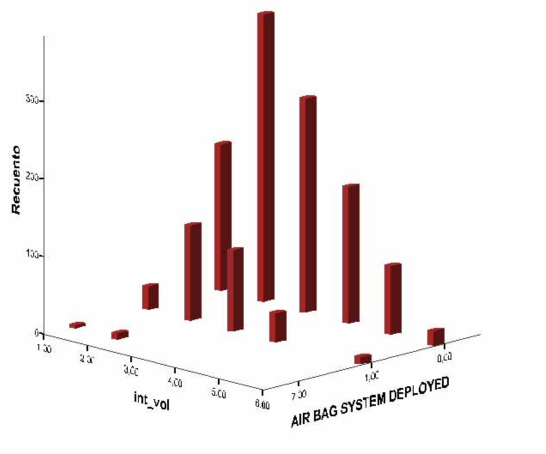

Figure 2. New geometries analysed.

The results shown in Figure 3 also presents very significant information on how intrusion is correlated with injury severity. As injury severity index increases its value the percentage of injured in crashes with small intrusion values is reduced.

In opposite to this effect the percentage of severe injured occupants in vehicles with higher values of intrusion magnitude increase.

Again the mentioned effect con be observed in both safety systems situations, without airbag and with airbag deployed.

It is very significant that in vehicles that being involved in an accident with driver airbag deployment, the severe injured occupants AIS3+ where driving vehicles that after the crash presented intrusions of the steering wheel higher than 15 cm.

With this value of steering wheel displacement the position of the airbag when the driver gets in contact with it, is much different from the initial situation. And the performance of the airbag can be quite different in regard with the design performances.

All these events conducted to develop an airbag system that could improve safety of drivers in all crashes situations and mainly in crashes with and without steering wheel intrusion.

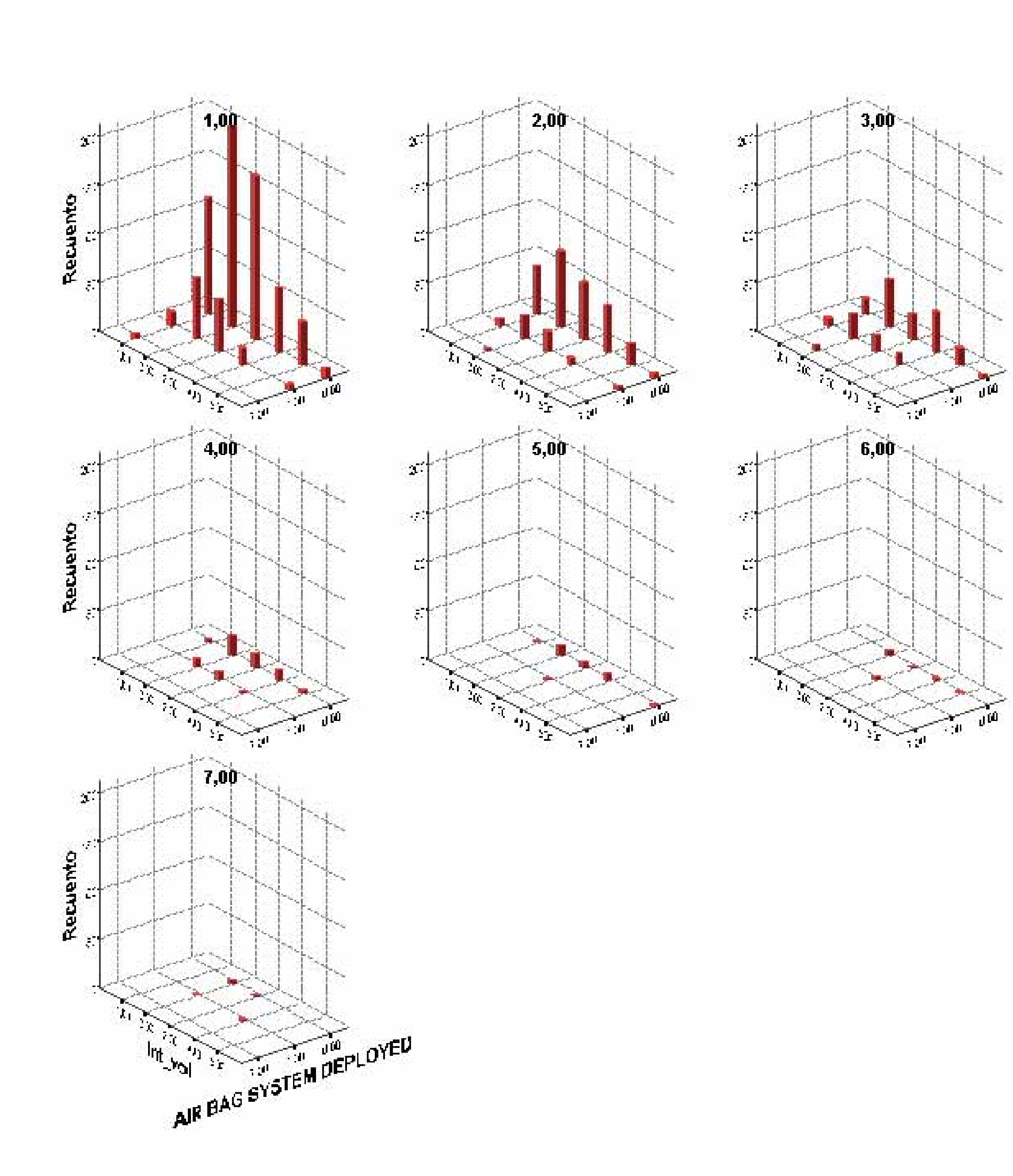

Figure 3. New geometries analysed.

4. VALIDATION

The validation of the model have been made comparing the results obtained in the instrumentation of the static, Body-block and sled test. The comparison gives a good correlation between test signals and simulation curves.

The Body Block test has been used to validate the airbag model under different conditions in order to have a robust model. The test procedure employs a torso-shaped body block which is impacted against

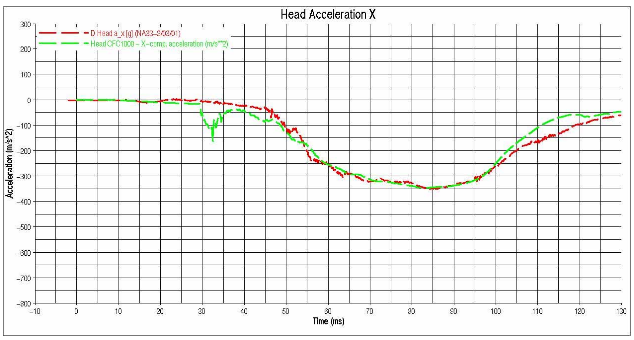

Figure 4. Head acc. curves

the steering control system at different velocities. One initial test is used for the correlation and afterwards 2 more tests were used to check and validate the MADYMO model. The signals analised in the correlation and validation of the model are steering wheel reaction forces measured in 6 axes, acceleration of the body, pressure inside the bag and the kinematics of the bag.

Also the sled test model show very similar results of both curves, numerical calculation and test signals. This validation have been made for Euro-NCAP with 50th and 5th percentile dummies and USA_NCAP with 50th percentile dummy.

Table 4. resume the results achieved with the model in comparison with the measurements of the sled tests.

It can be seen in the mentioned table that it has been achieved an excellent correlation with test results in all criteria with only one exception that is the chest deflection value. These results gives a good confidence in the model and makes possible to guarantee that the tendencies that the new geometries will show will be real

It is also presented in **Figures 2 to 4**, that also the curves obtained with the model do represent very precisely the kinematics and dynamics of the crash event.

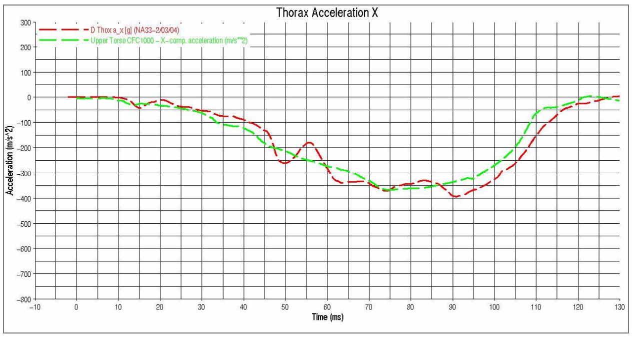

Figure 5. Thorax acc. curves.

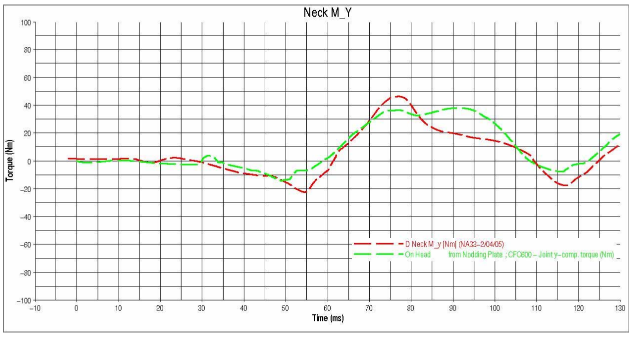

Figure 6. Neck My curves.

Table 1.
Test vs. Model results correlation.

	TEST Nº					
Dummy-loadings Dummy type Pulse	S-CA15091-086-16 50% Male US-NCAP	simulation	S-CA15091-086-19 50 % Male EURO-NCAP	simulation	S-CA15091-086-20 5% Female EURO-NCAP	simulation
HEAD HIC36	544	523	278	256	199	186
HEAD a3ms [g]	53.5	56	37.8	36	33.4	32
NECK max. Flexion [Nm]	75.4	74	39.7	38	26.9	25.4
NECK max. Extension [Nm]	-22.2	-21	-15.9	-14	-13.1	-7.1
THORAX a3ms [g]	59.1	57	39.7	37	41.1	36
THORAX smax [mm]/time [ms]	49,9 / 67,6	48	40,2 / 66,3	42	27,6 / 97,4	42
THORAX VC [m/s]	0.7	0.35	0.4	0.19	0.4	0.1
PELVIS a3ms [g]	79.1	87	56.3	57	36.3	39
FEMUR Fmax (right) [KN]	[-4.5] [0.2]	-4.4	[-3,37] [0,23]	-2.9	[-1,65] [1,26]	-2.2
FEMUR Fmax (left) [KN]	[-3] [0.68]	-2.66		-1.6	[-2,60] [0,20]	-2.1
FA [KN]	4.9	4.9	5	4.7	4.9	4.2
FB Th [KN]	6.4	4.8	3.9	4.4	3.5	3.9
FC [KN]	10.7	9.2	7.4	5.8	2.1	2.7
FD [KN]	3.7	4	3.8	3.8	3.8	3.4

Figure 7. Body Block Test.

rim with much higher probability that with rectangular one. This is one of the main advantages of these kind of bags that have sub abdominal energy absorbing shape.

Taking into account the new shapes designed they try to have the advantages of the rectangular shape improved retaining the arms and reducing in the early moments of the crash the kinetic energy of these body members. This effect makes that the efforts applied to the thorax by the arms are significantly lower.

This behaviour can be seen in table 2 comparing HIC 36 results. All three new shapes reduce this injury criteria value in comparison with both previous shapes (round and rectangular) for the crashes without steering column intrusion. In the case of steering column with intrusion all three shapes improve traditional round shape results and trebol 10 & 24 reduce also rectangular value. Shape trebol 25 has similar results that rectangular shape.

The same behaviour presents, for a3ms injury criteria, better results for new shapes in all cases (moving or fixed steering column).

Table 2.
Head/Neck Injury criteria Values

	HIC (36)	Head a3ms [m/s**2]	Neck Ext[Nm]	My Neck My Flex [Nm]
Round Fixed	301	406	27	46
Round Movil	232	382	42	27
Rectangular Fixed	303	399	15	81
Rectangular Movil	167	332	12	52
TREBOL10 Fixed	216	335	12	52
TREBOL 10 Movil	131	286	32	54
TREBOL 24 Fixed	220	340	10	54
TREBOL 24 Movil	151	317	31	40
TREBOL 25 Fixed	275	376	12	68
TREBOL 25 Movil	167	335	9	48

5. NUMERICAL SIMULATION ANALYSIS

The results from the analysis of the different shapes of bags are resumed in tables 2 to 5.

It is quite clear that the rectangular shape of the bag offers better results of Head Injury Criteria that the round one in crashes where the steering column have intrusion movements. Opposite to this advantage chest deflection has higher values for the rectangular shape than for the round one.

It is also very significative the increase in value for chest a_{3ms} for round bags in comparison with rectangular one. This specially high increase in value is due to the fact that with round shape the dummy has a hard contact with the steering wheel

Neck extension moment criteria (table 2) presents the round shape as the one with highest values in both types of crashes analysed, with and without intrusion. For crashes without steering column intrusion the best geometries for this criteria are trebol 24 (10Nm) and Trebol 10 and 25 (12 Nm). The highest value is shown for the round shape.

Focusing the analysis on the thorax (Table 3) area it can be seen that for crashes without intrusion of the steering column all shapes have similar a3ms values (interval 332-362 m/s^2). In cases with steering column intrusion it is significative that all shapes reduce the value obtained with the round shape.

Table 3.
Thorax Injury criteria Values

	Thorax a3ms [m/s**2]	Deflexion [mm]	Lower Torso a3ms [m/s**2]	Chest V*C [m/s]
Round Fixed	344	36	453	0,135
Round Movil	381	34	459	0,19
Rectangular Fixed	332	43	430	0,171
Rectangular Movil	338	40	458	0,231
TREBOL10 Fixed	341	36	459	0,11
TREBOL 10 Movil	338	30	462	0,087
TREBOL 24 Fixed	345	39	458	0,133
TREBOL 24 Movil	326	35	458	0,148
TREBOL 25 Fixed	362	42	449	0,167
TREBOL 25 Movil	336	40	455	0,216

Thorax deflection criteria without intrusion of the steering column have best values for round shape and for trebol 10 solution this is due to the fact that these geometries do have less retaining area in the thorax area. In cases with intrusion the best results are for trebol 10 solution with similar values for round and trebol 24 solution (34 and 35 mm respectively).

respectively). The highest interaction of the other solutions Rectangular shape and trebol 25 makes that these geometries perform worse in regard with this criteria (0,171-0,167).

Crashes with significant movements of the steering wheel also present the highest extension moment with the round shape (42 Nm) and the geometries that perform best are rectangular and trebol 25 (12

Table 4.
Belt forces

	FD_retractor [N]	FA_shoulder [N]	FB_thorax [N]	FC_anclaje [N]
Round Fixed	3430	4446	4706	7084
Round Movil	3463	4471	4848	7325
Rectangular Fixed	3396	4451	4326	6549
Rectangular Movil	3376	4426	4691	7129
TREBOL10 Fixed	3403	4455	4568	7165
TREBOL 10 Movil	3425	4434	4797	7399
TREBOL 24 Fixed	3382	4410	4543	7097
TREBOL 24 Movil	3388	4411	4729	7381
TREBOL 25 Fixed	3396	4449	4365	6938
TREBOL 25 Movil	3353	4393	4620	7235

Table 5.
Legs Injury criteria Values.

	F_Femur Left [N]	F_Femur Right [N]
Round Fixed	1357	967
Round Movil	1278	966
Rectangular Fixed	1534	906
Rectangular Movil	1293	868
TREBOL10 Fixed	1357	989
TREBOL 10 Movil	1263	900
TREBOL 24 Fixed	1368	944
TREBOL 24 Movil	1309	884
TREBOL 25 Fixed	1492	934
TREBOL 25 Movil	1323	886

For VC criteria in non intrusion crashes best solution is trebol 10 followed by trebol 25 and round shape both with similar values (0,133-0,135

and 9 Nm) the other new geometries have middle values.

The rest of the parameters analysed (see tables 4 and 5) have values very similar for all the geometries studied and both kinds of steering column crash behaviour. These parameters are belt anchorage forces, Femur forces and lower torso.

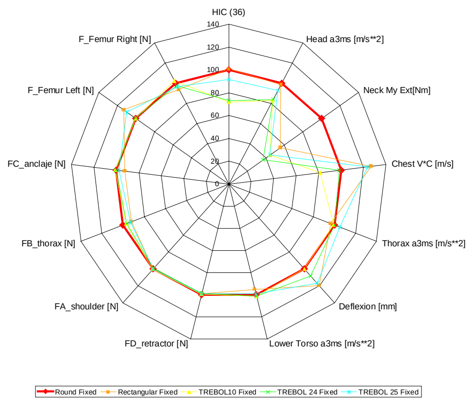

Figure 8. Non intrusion injury criteria percentage values.

Figures 6 and 7 show the percentage of variation of each crash parameter or injury criteria analysed considering 100% the value for the traditional rounded shape.

Starting the analysis by the non steering column intrusion crashes simulations (Figure 6) it is remarkable that trebol 10 and 24 reduce the injury risk in comparison with rounded solution in HIC 36, Head a3ms, Neck My extension moment and thorax a3ms. And the rest of the analysed parameters or criteria are very similar to the reference geometry (Rounded).

The improvement achieved with both solutions in HIC 36 is 41% for trebol 10 geometry and 35% for trebol 24. Both geometries present a reduction of neck extension moment near 25%. Also VC criteria improvement can be evaluated in 55% for the trebol 10 solution and near 22% for trebol 24 geometry.

Trebol 25 and rectangular shape present advantages in the Head injury criterias but Thorax Deflection and VC criteria are outside the reference 100% area.

These results lead the optimum geometries for these kind of vehicle crash behaviour, as geometries near trebol 10 and trebol 24. With the subabdominal retaining area reduced in comparison with trebol 25.
The next step is to analyse the results of the different geometries considering the movement of the steering column (see Figure 7).

Again the curves for solutions trebol 10 and trebol 24 are inside the reference area defined by the rounded solution for most of the criterias and parameters and the ones that are not inside have

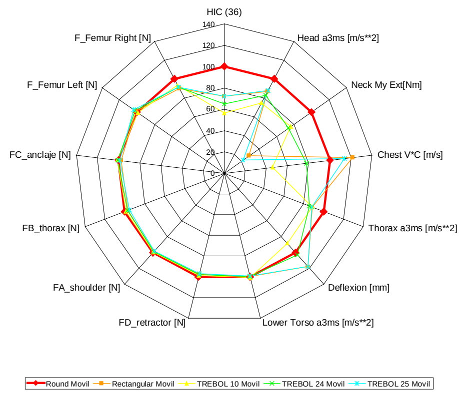

Figure 9. Intrusion injury criteria percentage values.

very closed values to the reference.
In this simulations the worse HIC 36 ms is performed by the reference geometry (rounded shape) and best solutions are again trebol 10 and 24 with an improvement near 42% for trebol 10 and 35% for trebol 24. Rectangular and trebol 25 solutions present similar reduction of HIC value around 15%.

The same conclusions are obtained for Head a3ms with trebol 10 and trebol 24 ahead of the improvement (25% and 18% respectively).

Next injury criteria to be analysed is Neck extension Moment My Round shape present the worst value and trebol 10 and 25 reduce this criteria value in 22% While rectangular and trebol 25 improve it over 70%.

Next step in the analysis of results is to review thorax parameters. VC criteria has a similar behaviour than it had in the analysis of crashes without movements of the steering wheel. In fact again rectangular and trebol 25 solution increase the criteria value around 20%, while trebol 24 reduces the valur in 20% and trebol 10 around 55%.

All shapes have better results in thorax a3ms criteria than round one being stimated the reduction in 8%. This reduction is very similar in all different shapes analysed.

Thorax deflection criteria shows as best solution trebol 10 12% lower value than round shape and trebol 24. On the opposite side are rectangular shape and trebol 25 with 118% higher value than the traditional solution.

As it was referred for the simulations without significant movements of the steering column, all the other parameters analysed do not have changes for each shape. Lower torso a3ms, Belt forces and femur criteria.

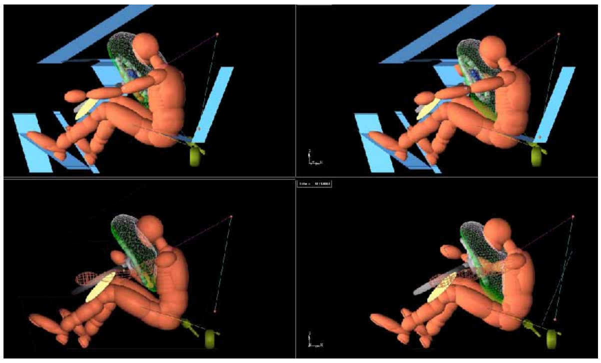

Figure 10. Rectangular and Rounds Shapes

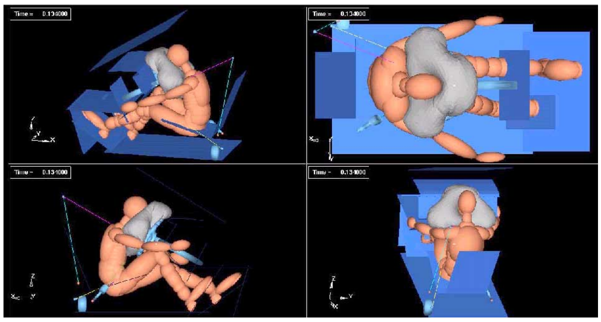

Figure 11. Trebol 24 without SC movements

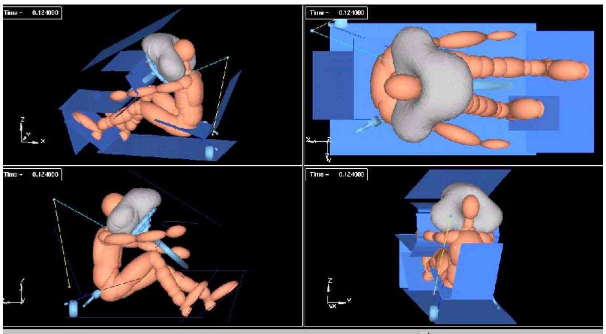

Figure 12. Trebol 24 with SC movements

6. KINETIC ANALYSIS.

The new shapes produce a greater area of contact with the airbag, mainly in the upper thorax, Shoulders and arms that reduce in the early moments the kinetic energy of the dummy.

This reduction is mainly recognised in the acceleration results of Head and Thorax, where the new shapes reduce these parameters.

Also the main advantage of the rectangular shapes, with sub abdominal area is the retention that provides to the dummy when some significant movements of the steering column occur. This is mainly due to the reason that this area still retains the thorax when intrusion is present.

Another important dynamic process that has to be mentioned is that the sub abdominal area ameliorates Head parameters, thorax ones do not perform better because of the retention that the airbag makes in this area. On the other hand this interaction airbag body is the one that reduces the chance of hitting the steering wheel rim when important movements of it have occurred.

This is the reason why there have been designed numerous shapes and why trebol 24 is a compromising solution.

7. CONCLUSIONS

The present work shows a new airbag shape development that performs much better in near all the criteria analysed. Mainly the improvement is due to the effect of retaining the arms in the early moments of the crash minimizing the effort that they apply to the upper thorax of the dummy.

This solution does not have all its functionality when the steering wheel have important intrusion movements, but the design have been optimised, to obtain a restraint systems that do not penalize this kind of crashes. This penalisation is mainly compared to rectangular shape that has the best performance in this kind of crashes.

Next steps of the work will analyse the risks of these non asymmetric solutions when the steering wheel position at the beginning of the crash is not the straight position, and in offset crashes with rotation of the steering wheel.

This development in safety system performance has been developed in parallel with a mechanical steering solution that guarantees the right position of the airbag independently from the steering wheel situation or movements.

This mechanical development has allowed to define highly non symmetrical bags with the main objective of improving safety in all crashes situations.

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